

**Gen-IV:
Pb or Pb-Bi Cooled “Battery”
Concept Set, (L6)
Gen-IV Quarterly Meeting
June 25-27, 2002
Boston, MA**

- *Description:*
- *Targeted Payoffs & Benefits of Recommended R&D*
- *Technical Issues*
- *R&D Needs (Viability R&D Phase)*

Presenter: David Wade (TWG-3)

Description: Pb, Pb-Bi Battery Concept Set, (L6)

Description

- **Small (125 to 400 MW_e)**
- **Transportable (Factory Built Turnkey Plant; Rapid Installation & revenue generation)**
- **Long Refueling Interval: 15-20y; (internal conversion ratio \geq 1.0)**
- **Cassette or Entire Module refueling (Full service fuel cycle provider)
(No Refueling Equipment on Site)**
- **Derated Power Density (LWR range) (Natural Circulation Cooled)**
- **Passive Load Follow/Passive Safety (No safety Functions for BOP)**

Options

- **High Temperature: Alternative Energy Products (Process Heat Hydrogen, O₂, Desalinated water)**

Concept Set L6: Small Lead or LBE Cooled Reactors, Cartridge Refueling, ~Pyroprocess Recycle

Concept	Know As	Size (MWe)	Fuel	Outlet Temperature (°C)	Fuel Cycle	Country	Sponsoring Organization	
M11	ENHS (LBE)	125 (thermal)	Metal or nitride	564/543	AIROX or pyroprocess	U.S.	U. California	
M13	STAR-LM (LBE)	120-160	U-Pu-MA nitride	~550	Pyroprocess	U.S.	Argonne	
M17	STAR-H2 (Pb)	400 (thermal)	U-Pu-MA Nitride	780	Pyroprocess	U.S.	Argonne	
M21	Integrated lead Reactor (Pb)	~350	Metal or nitride	540 (and up)	Pyroprocess	Brazil	IEAv/IPEN	
Related Near Term Industrial Interest in Battery Concepts: Liquid metal; (Water offered for sale by OKBM; others)								
M2	VK-75/100 (Pb-Bi)	75-100	UO ₂ UN MOX	~500	Options (see fuel)	Russia	IPPE/ Hydropress	<u>Status</u> Offered for Sale
M24	4S (Na)	50	UZr	~525	Pyroprocess	Japan	Toshiba/CRI EPI	Na: Title 1 design Pb-Bi: Concept design

Targeted Payoffs: *Extended Client Base:* *Extended Products*



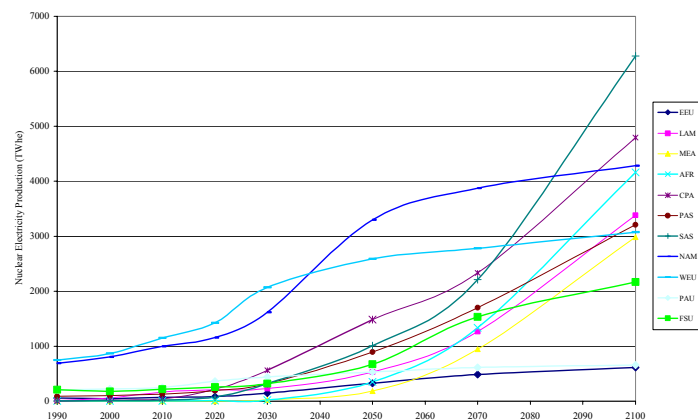
Targeted Market Expansion

- **Developing Country Clients**
 - **Sparse Grid**
 - **Tight Capital Availability**
 - **No Interest (or capacity) to emplace a Full Fuel Cycle Infrastructure**
 - **Nonproliferation Advantages to Community of Nations: Regional Fuel Cycle Centers (localized international oversight of bulk fuel and waste management)**
- **Merchant Plant Clients for New Energy Products in Deregulated Markets**
 - **Hydrogen, Process Heat, Potable Water**
 - **Super safe/minimal staffing/urban siting**
 - **Financial Conditions: High interest/quick return on capital required**

Benefits Derived by Developing L6 Concept Set in Gen-4

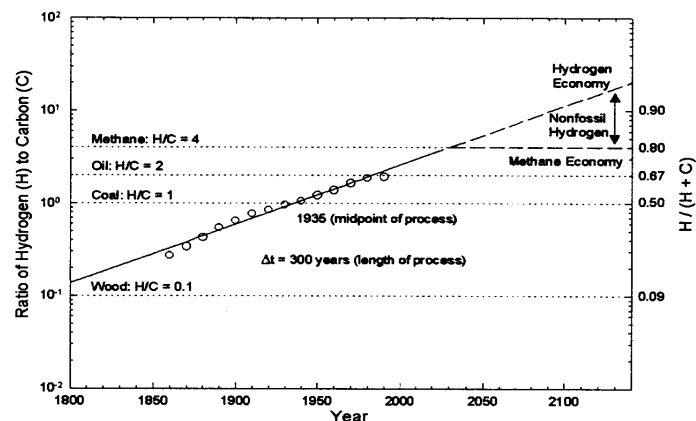
- **L6 concepts fill impending Market Needs, complimentary to other Gen-4 concepts**
- **Numerous Innovations are Proposed -- which can benefit other Gen-4 concepts also:**
 - **e.g., Supercritical CO₂ Brayton Cycle (could benefit L1/L2 Na fast reactors)**
 - **Thermochemical Water Cracking (GFR, VHTR)**
 - **Modern high temperature materials and fabrication (composites, coatings); mass production fabrication practices; lift pumps, direct contact and close coupled heat transport (benefits numerous concepts)**
 - **Pb & Pb-Bi technology (leverages international interest: Europe, Japan, Russia)**

TWG-3 Liquid Metal

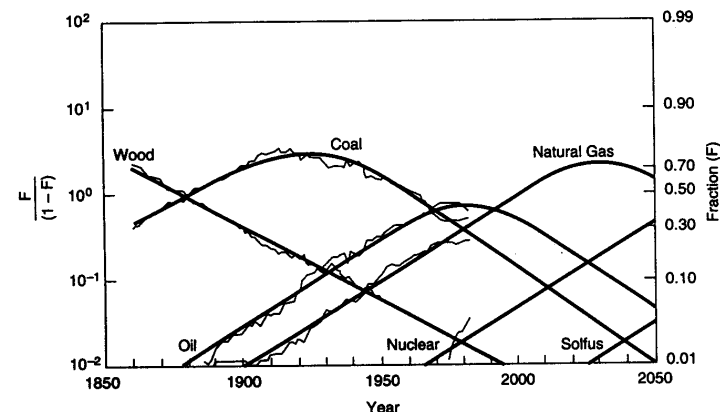


Geographical Distribution of Nuclear Electricity Demand (TWh/yr) in the Scenario B Case³

³EEU = Central & Eastern Europe; LAM = Latin America; MEA = Middle East & North Africa; AFR = Sub-Saharan & Southern Africa; CPA – Centrally Planned Asia & China; PAS = Pacific OECD (Japan, Australia, New-Zealand); SAS = South-East Asia; NAM – North America; WEU = Western Europe; PAU = Other Pacific Asia; FSU = Former Soviet Union



Global primary energy substitution from 1860 to 1982 and projections for the future, expressed in fractional market shares (F). NOTE: Smooth lines represent model calculations and jagged lines are historical data. “Solfus” is a term employed to describe a major new energy technology, for example, solar or fusion. SOURCES: Grubler and Nakićenović (1988) and Makićenović (1990)



Ratio of hydrogen (H) to carbon (C) for global primary energy consumption since 1860 and projections for the future, expressed as a ratio of hydrogen to carbon (H/C). SOURCE: Ausubel (1996) and Marchetti (1985)>

- 4-Step Thermochemical Cycle

	Temp (°C)	Heat Flow	Purpose
1. $\text{Ca Br}_2(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{CaO}(\text{s}) + 2\text{HBr}(\text{g})$	700-750	in	Crack water With Ca Br ₂ and heat
2. $\text{Ca O}(\text{s}) + \text{Br}_2(\text{g}) \rightarrow \text{Ca Br}_2(\text{s}) + \frac{1}{2} \text{O}_2(\text{g})$	500-600	~neutral	Regenerate Ca Br ₂ using Br ₂
3. $\text{Fe}_3\text{O}_4(\text{s}) + 8\text{H Br}(\text{g}) \rightarrow \text{Fe Br}_3(\text{s}) + 4\text{H}_2\text{O}(\text{g}) + \text{Br}_2(\text{g})$	200-300	out	Regenerate Br ₂ using rust
4. $3\text{FeBr}_3(\text{s}) + 4\text{H}_2\text{O}(\text{g}) \rightarrow \text{Fe}_3\text{O}_4(\text{s}) + 6\text{HBr}(\text{g}) + \text{H}_2(\text{g})$	550-600	in	Regenerate rust using water & heat
- H₂ released in Step 4; O₂ released in Step 2
- Heat Supplied at ~725°C in Step 1 and at ~575°C in Step 4

UT-3 Process for Cracking Water

Potable water becoming 21st century's new gold

By Joan Lowy

SCIENCE HOWARD NEWS SERVICE

Water will be to the 21st century what oil was to the last — vast fortunes will be made by controlling it, and nations will go to war to preserve access to it.

In a world in which fresh water is increasingly scarce, that axiom is being taken to heart in the boardrooms of some of the globe's most powerful corporations. In nearly every corner of the planet, international water conglomerates are vying to sign operating contracts, make deals, buy rights and acquire local water supply and treatment companies.

It's a worldwide water rush.

Given that less than 1 percent of the Earth's water is drinkable, the corporate betting is that the price of water can only go up: Fresh water is a finite resource for which there is no substitute.

Estimates of the value of the annual global market for water range from \$200 billion to \$800 billion. Already, an estimated 300 million to 400 million people receive water through privately owned or operated water companies.

And the biggest, most underexploited water market on Earth is the United States, with estimated annual revenues of \$90 billion. About 86 percent of the municipal water in the United States is delivered by public utilities, while only 13 percent is delivered by private companies. But water companies are swiftly expanding their foothold in the United States

Water resources worldwide

Countries are characterized according to the amount of water available for consumption each year. Those areas with less than 265,000 gallons available per person each year are considered to be water-scarce, while those with less than 450,000 gallons available are considered water-stressed.



Source: U.N. Population Division

SI-MIS graphics

through operations and maintenance contracts for water delivery and wastewater treatment services, or by assuming temporary or permanent ownership of water utilities.

By comparison, 85 percent of French customers get their water through privately owned or operated water utilities. In the United Kingdom, nearly all water services have been privatized for more than a decade.

The two biggest global water companies are French — Vivendi Environnement and Suez Lyonnaise des Eaux, with more than 100 million customers each. During the past three years, both companies have made a

major push to establish themselves in the U.S. market by acquiring American water companies.

In 1999, Vivendi purchased U.S. Filter Corp. for \$6 billion in cash. The same year, Suez — which built the Suez Canal in the 1860s — paid \$1 billion for United Water Resources and bought two major U.S. water treatment chemical producers, Nalco and Calgon, for \$4.5 billion.

The largest private water supplier in the United States is the giant German utility RWE, with 14 million customers. In September, RWE announced its purchase of American Water Works, headquartered in Voorhees, N.J., in a \$7.6 billion deal.

American, which itself had been gobbling up smaller water companies, was the largest publicly traded U.S. water company, supplying water and wastewater service to 1,400 communities in 23 states. RWE now has more than 50 million customers worldwide.

The only U.S. company that has been a major player in the global water market is Enron, the Houston-based energy trading company. Since filing for Chapter 11 bankruptcy in October, Enron has been trying to sell its water subsidiary, Azurix, in an effort to raise cash. One of the companies that have expressed interest in buying Azurix is RWE.

Private water companies contend they can provide water services more cheaply and efficiently than governments or public utilities. Their services will be essential, the industry argues, if the world hopes to stave off the impending global fresh-water crisis that's forecast to occur as water-scarce regions scramble to find new supplies to quench their growing populations.

Presently, at least 50 percent of municipal water is wasted through leakage in developing nations, according to the World Bank. In the Philippine capital of Manila, for example, 57 percent of municipal water is lost to theft and leakage. More than two-thirds of irrigation water never reaches crops in the Third World because of inefficiencies. The World Health Organization estimates that more than 1 billion people currently do not have access to clean water.

In the United States, many cities are faced with modernizing an aging water infrastructure of pipes and pumps that dates back to the early- and mid-20th century. New York City's leaky Delaware Aqueduct has been losing as much as 1 billion gallons a month.

At the same time, water utilities are being asked to meet tighter environmental regulations to protect water quality. The cost to repair, replace and improve the nation's water infrastructure is estimated at nearly \$1 trillion during the next 20 years, creating a looming economic crisis for many cities.

During the past few years, dozens of cities ranging from Atlanta to Indianapolis to Jersey City have signed long-term contracts with large water companies to operate and maintain their water services or even to assume ownership of local water utilities on a temporary but long-term basis.

One of the attractions of privatizing water services is that private companies are often willing to make tough decisions that elected officials would rather forgo, such as raising water rates or cutting work forces.

"There is a price to be paid for clean, safe water," said Kathy Shandling, vice president of International Private Water Association, an industry trade group. "This is going on in this country now, where people who are suddenly getting water bills who didn't get them before are saying, 'Water is an act of God. I shouldn't have to pay for it.'"

- "Many of the wars in this century were about oil, but wars of the next century will be about water." (Ismail Serageldin, Vice President, World Bank, 1996)
- "The next war in the Middle East will be over water, not politics." (Boutros Boutros-Ghali, Secretary General, United Nations, 1991)

Economic Threat May Push Pakistan to Nukes

(Nadeem Iqbal, Inter Press Service)

http://story.news.yahoo.com/news?tmpl=story&u=oneworld/20020204/wl_oneworld/1032_1012817396

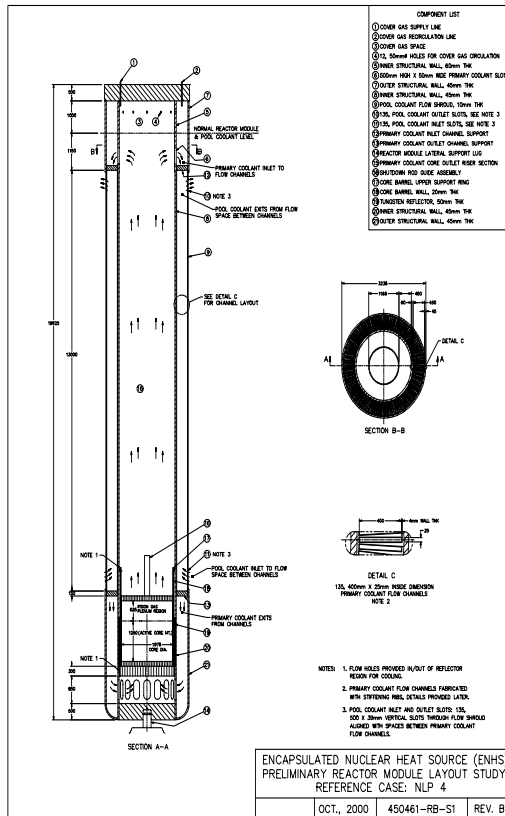
Monday, February 4

Pakistan has laid down scenarios under which it may use nuclear weapons as a last resort -- if its survival is threatened by India not only militarily but by strangling its economy or stopping access to shared water resources, says a new report by Italian nuclear physicists who visited the country recently.

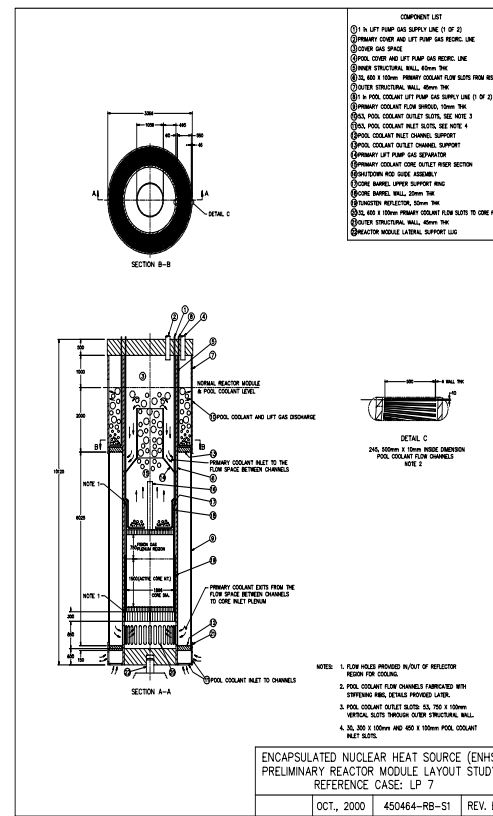
Quoting the top Lt Gen Khalid Kidwai of the nuclear Strategic Plan Division (SPD), the report outlined Pakistan's four nuclear thresholds, adding that "the nuclear weapons are aimed solely at India".

Targeted Payoffs Drive the Required R&D

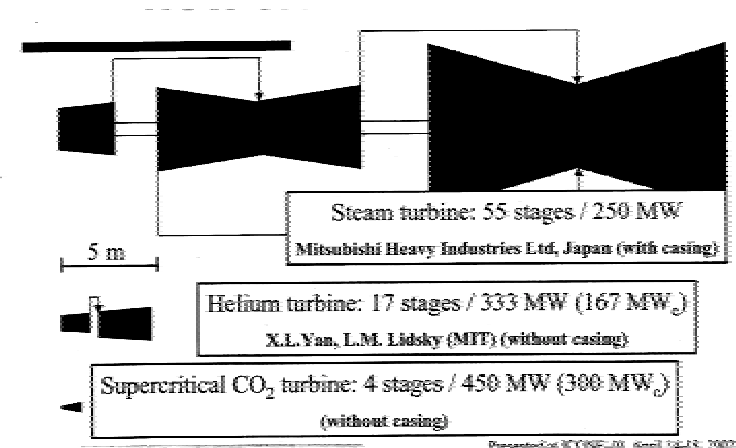
- **New Energy Conversion** → **Need: Raise Core Outlet Temperature**
Approach: → **Go to Pb Coolant**
→ **Go to Nitride Fuel**
→ **Outcome: Need for Advanced Materials & Fuels**
 - R&D** {
 - **Nitride Fuel Performance, Recycle; Refab**
 - **Composites, ceramics, coatings**
→ **Outcome: Need New Energy Converters**
 - R&D** {
 - **Water Cracking Plants**
 - **SC CO₂ Brayton Cycles**
- **New Markets for Small Turnkey Plants** → **Need: Overcome Loss of Economy of Scale**
Approach: → **High Efficiency Energy Conversion (gas turbines, H₂)**
→ **Mass Production**
→ **Simplify/Reduced Components**
→ **Outcome: Need for Advanced Fab/Construction**
 - R&D** {
 - **Advanced materials/forming/joining**
 - **Modularization**
 - **Simplified Fuel Fab**



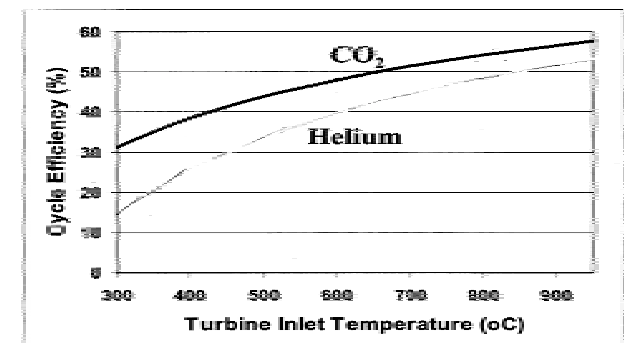
ENHS1
Reference ENHS module
without a lift-pump



ENHS2
Reference ENHS module
with a cover-gas lift-
pump



Turbine Sizes
HOW SMALL IS SMALL?



Presented at ICONE-10 April 14-18, 2002

Advantage of Recompression Supercritical CO₂ Brayton
Cycle over the Helium Brayton Cycle

Top Priority Technology-Based R&D - (1)

- ***Inservice Materials Compatibility: New Coolant New Temperatures, New Fuel***
 - ***R&D***
 - : Structures***
 - : Heat Exchangers : Tube Interfaces***

<i>Pb or Pb-Bi/steam</i>	<i>and</i>	<i>HBr + Steam / Steam</i>
<i>/ SC CO₂</i>		<i>/ CO₂</i>
<i>/ He</i>		<i>/ He</i>
<i>/ Molten Salt</i>		<i>/ Molten Salt</i>
 - ***Materials candidates include advanced materials; advanced fabrication***
 - Si C or Zr N composites or coatings***
 - Vanadium alloys***
 - Others***

Top Priority Technology-Based R&D (2)

Energy Conversion Equipment/Processes

- **New Options**
 - : **Supercritical CO₂ Brayton Cycle**
 - : **Ca-Br Water Cracking**
 - : **Desalinization Bottoming cycles**
- **Required R&D**
 - **Materials (discussed above)**
 - **Sc CO₂ Brayton Cycle** : **Thermodynamic Optimization**
Recuperator Design, IHX Design;
Turbine Design
 - **Ca-Br Water Cracking** : **Materials (discussed above)**
Ca Support
Properties of Reactants
Rate Constants
Flowsheet/Bench Scale/Prototype
 - **Desal Bottoming Cycle** : **Overall BOP Heat Balance**
Optimized Hybrid Cycles

Top Priority Technology-Based R&D (3)

Fuel Cycle

- ***Nitride Fuel: High Potential for L6 Mission***
 - ***Compatible with Pb and good to high temperature***
 - ***High density; high thermal conductivity → Passive Safety***
- ***Required R&D***
 - ***N15 Enrichment and Recovery during recycle***
 - ***Pyro Recycle/Insitu Front End dissolution, and back end reconversion***
 - ***Vibro pac remote refabrication***
 - ***Fuel/Clad/Coolant Performance Testing***
 - Properties: unirradiated; irradiated***
 - Normal & operational transient testing***
 - Upset Condition Testing***
 - Severe Event phenomenology testing***
 - ***Cladding Options: SiC or ZrN Composites, Ceramics, Coatings, Vanadium Alloys***

Major Institutional Issues:

- **Market Penetration is based on (for nuclear) institutional paradigm shifts**
 - **Goal 1: Facilitate Nuclear as an energy supply component in developing world**
 - **Small Turnkey Plants delivered ready to go**
 - § **Small buyin cost; short time to revenue generation**
 - § **BOP (No safety function) can be built indigenously (local jobs)**
 - **Full Service Fuel Cycle Services Provided by Regional Fuel Cycle Center (Consortia Owned by Clients); International Oversight**
 - § **No expense of emplacing an indigenous fuel cycle infrastructure**
 - § **Energy Security for Client; Nonproliferation Assurance for World**
 - **Resulting Institutional Issues and paradigm shift**
 - § **Supplier assumes risk of supplying large quantities of a commodity product; client risk is reduced**
 - § **International consensus needed for acceptability of regional fuel cycle centers – which also include waste management**
 - **Goal 2: Broaden Nuclear's Role in Energy Products (H_2 , Water, Process Heat)**
 - **Approach**
 - **High Temperature, Super Safe Plants, for near urban siting (where the jobs are)**
 - **Institutional Issues of Expanding Nuclear's role beyond electricity only**
 - + **Link perception of "Clean, sustainable" Nuclear Resource to "clean" emission free synthetic fuel (H_2) – supplying nonelectric 2/3 or energy market**
 - + **Prerequisite: achieve perception of waste, cost issues of nuclear solved**